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Optimal New Energy Vehicle Production Strategy Considering Subsidy and Shortage Cost

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Abstract

In this paper, we present an analytical model to investigate how the optimal production strategy of new energy vehicles (NEVs) is influenced by subsidy, market fluctuation, and loss aversion. We find that a loss averse decision maker may produce more production quantity than the optimal quantity in risk neutrality under the certain conditions. We demonstrate that the expected utility is substantially influenced by subsidy, loss aversion, and the shortage cost. Although the relationship between subsidy and loss aversion is not straightforward when considering shortage cost, subsidy may play a role to regulate the possible overages and shortages in NEV manufacturing. Implications to both policy makers and practitioners are discussed.

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1. Introduction

The market for new energy vehicle (NEV) in China becomes booming. NEV refers to electric vehicle, fuel cell battery vehicle, and plug-in hybrid electric vehicle. In the first ten months of 2014, a total of 46,935 NEVs have been produced[1]. And a total of 38,163 NEVs have been sold in the first nine months[2], surging by 2.8 times compared to the total sales volume in the same period of 2013. A series of major factors contribute to the NEV market growth, including the extension of the subsidy program for NEV manufacturers with a gradual reduction beyond 2015, the purchase tax exemption for consumers, more NEV models and types available on the market, the restrictions on fuel oil vehicles, and the

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advancement of technology (such as the increased battery capacity with a greater cruising range etc.), to name a few.

The recent surge in NEV demand reminds the managers to consider the possible influence of stockout problem. In fact, the media has already reported the battery supply shortage which in turn causes the shortage of NEV supply[3]. In addition to the market fluctuation, managers of NEV manufacturer have to consider a number of other influential factors when making production decision, including subsidy and decision bias. On one side, subsidy drives down the relatively high selling price to make the NEV more economically competitive. On the other side, the manager's decision making behavior is governed by human behavioral and psychological rules, such as loss aversion[4][5][6][7][8][9], which may cause decision bias. The decision bias further complicates the decision process as it brings another uncertainty when predicting the influences of government incentives on promoting NEV production and adoption.

In this paper, we investigate the loss averse NEV manager's decision making process with overage risk, underage risk, and subsidy. The analytical work is based on the loss averse newsvendor model (see [10] and [11] for reviews of the risk neutral newsvendor model). Due to the different research focuses, previous studies on loss averse newsvendor model assume that the unsatisfied demand is lost, see for example [12][13][14][15]. In this paper, we show how the shortage cost substantially influences on the manager's optimal quantity and the effect of subsidy. We also reveal the interaction mechanism among subsidy, loss aversion, the optimal production quantity, and the expected utility. In the following, we present the analytical model with shortage cost in Section 2. In Section 3, we derive the optimal solution and the relevant properties of the proposed model. We discuss the results and make concluding remarks in Section 4.

2. The analytical model

Consider a situation where a manager of a NEV manufacturer facing stochastic demand, x, with the probability density function $f(x)$ and the cumulative distribution function $F(x)$. The manager has to decide how many NEVs to produce well in advance before the selling season starts. Let p be the per unit selling price of the product, c the per unit production cost, s the per unit salvage value, and g the per unit goodwill cost due to shortage, $s > 0$, $g > 0$. Let Y be subsidy to NEV manufacturer, $Y > 0$. Following [9], we assume the NEV manager knows that his company receives the per unit subsidy Y for the realized demand, indicating that each product has a higher per unit revenue ($p + Y$). Different from [9], we incorporate the shortage cost here. The profit function $\pi(Q, x)$ can be written as follows:

$$\pi(Q,x)=\begin{cases}(p+Y)x+s(Q-x)-cQ & \text{if } x\le Q\text{, the overage situation}\\(p+Y)Q-g(x-Q)-cQ & \text{if } x>Q\text{, the underage situation}\end{cases} \tag{1}$$

From the profit function (1), the manager knows that there are two breakeven points. Let q_o and q_s be the breakeven quantities corresponding to the overage and the shortage cases, respectively. The q_o and q_s can be written in the following manners:

$$q_o(Q)=\frac{(c-s)Q}{p+Y-s} \tag{2}$$

$$q_s(Q)=\frac{(p+Y+g-c)Q}{g} \tag{3}$$

When the demand is less than q_o or more than q_s, the manager knows that the profit is below the relevant breakeven points, and hence is negative. According to loss aversion theory[4][6], the manager in this case is more sensitive to the losses than the equivalent gains (or profits) with the breakeven points as reference point. Let λ be the loss aversion coefficient, $\lambda > 1$. Let $EU[\pi(Q, x)]$ and $EU(\pi_{\lambda s})$ be the risk neutral and the loss averse decision maker's expected utility, respectively. Using the breakeven points $\pi_1(q_o) = \pi_2(q_s) = 0$ as the reference point, the model to maximize the loss averse manager's expected utility can be written in the following manner:

$$Max\, EU(\pi_{\lambda s}) = EU[\pi(Q,x)] + (\lambda-1)\int_{x=0}^{q_o(Q)}[(p+Y)x + s(Q-x) - cQ]f(x)dx \\ + (\lambda-1)\int_{x=q_s(Q)}^{\infty}[(p+Y)Q - g(x-Q) - cQ]f(x)dx \tag{4}$$

As shown in Eq.(4), the two breakeven points, i.e. the overage breakeven point and the underage breakeven point, are served as the reference point. If $g = 0$, Eq.(4) reduces to the loss averse newsvendor model without the shortage cost. If $\lambda = 1$, the last two parts in Eq.(4) are zero, which means there is no reference dependence and the model (4) reduces to the standard subsidized newsvendor model.

3. The properties of the model

In this section, we present the properties of the model regarding the optimal quantity, the maximum expected utility, and the effects of subsidy on NEV production.

Proposition 1. Eq. (4) is concave in Q and there exists a unique optimal solution as shown in the following Eq. (5).

$$F(Q^*_{\lambda s}) = \frac{(p+Y+g-c) - (\lambda-1)(c-s)F(q_o(Q)) + (\lambda-1)(p+Y+g-c)[1-F(q_s(Q))]}{p+Y+g-s} \tag{5}$$

Proof of Proposition 1

Taking the first and second derivatives of $EU(\pi_{\lambda s})$ with respect to Q in Eq.(4), respectively, we have:

$$\frac{\partial EU(\pi_{\lambda s})}{\partial Q} = \lambda(p+Y+g-c) - (p+Y+g-s)F(Q) - (\lambda-1)(c-s)F(q_o(Q)) - (\lambda-1)(p+Y+g-c)F(q_s(Q))$$

$$\frac{\partial^2 EU(\pi_{\lambda s})}{\partial Q^2} = -(p+Y+g-s)f(Q) - (\lambda-1)\frac{(c-s)^2}{p+Y-s}f(q_o(Q)) - (\lambda-1)\frac{(p+Y+g-c)^2}{g}f(q_s(Q)) < 0$$

As $\frac{\partial^2 EU(\pi_{\lambda s})}{\partial Q^2} < 0$, Eq.(4) is concave in Q. Using the first order condition, we can derive the loss averse manager's optimal production quantity, as shown in Eq.(5).

Q.E.D.

Proposition 2. Define $\pi_{loss} = (p + Y + g - c)F(q_s) + (c - s)F(q_o)$.

(1) The optimal production quantity $Q_{\lambda s}{}^*$ is increasing in the shortage cost g and subsidy Y.

(2) If $(p + Y + g - c) > \pi_{loss}$, the optimal production quantity $Q_{\lambda s}{}^*$ is increasing in the loss aversion coefficient λ and is more than the optimal quantity Q^* in risk neutrality, i.e., $\partial Q^*_{\lambda s}/\partial\lambda > 0$ and $Q^*_{\lambda s} > Q^*$. Otherwise, $Q_{\lambda s}{}^*$ is decreasing in λ and is less than the optimal quantity in risk neutrality.

Proof of Proposition 2

For 2(1), taking the partial derivative of Q with respect to g, we have:

$$\frac{\partial Q_{\lambda s}}{\partial g}=-\frac{\partial^2 EU(\pi)/\partial Q_{\lambda s}\partial g}{\partial^2 EU(\pi)/\partial Q_{\lambda s}^2}=\frac{\lambda-F(Q)-(\lambda-1)F(q_s(Q))}{(p+Y+g-s)f(Q)+(\lambda-1)\frac{(c-s)^2}{p+Y-s}f(q_o(Q))+(\lambda-1)\frac{(p+Y+g-c)^2}{g}f(q_s(Q))}>0$$

Similarly, taking the partial derivative of Q with respect to Y, we have:

$$\frac{\partial Q_{\lambda s}}{\partial Y}=-\frac{\partial^2 EU(\pi)/\partial Q_{\lambda s}\partial Y}{\partial^2 EU(\pi)/\partial Q_{\lambda s}^2}=\frac{\lambda-F(Q)-(\lambda-1)F(q_s(Q))}{(p+Y+g-s)f(Q)+(\lambda-1)\frac{(c-s)^2}{p+Y-s}f(q_o(Q))+(\lambda-1)\frac{(p+Y+g-c)^2}{g}f(q_s(Q))}>0$$

For 2(2), taking the partial derivative of Q with respect to λ, we have:

$$\frac{\partial Q_{\lambda s}}{\partial \lambda}=-\frac{\partial^2 EU(\pi)/\partial Q_{\lambda s}\partial \lambda}{\partial^2 EU(\pi)/\partial Q_{\lambda s}^2}=\frac{(p+Y+g-c)[1-F(q_s(Q))]-(c-s)F(q_o(Q))}{(p+Y+g-s)f(Q)+(\lambda-1)\frac{(c-s)^2}{p+Y-s}f(q_o(Q))+(\lambda-1)\frac{(p+Y+g-c)^2}{g}f(q_s(Q))}$$

Note that the above denominator is positive. If $(p+Y+g-c)[1-F(q_s(Q))]-(c-s)F(q_o(Q))>0$, then $\partial Q_{\lambda s}/\partial\lambda>0$. Since Q^* maximizes the profit in risk neutrality (i.e., λ = 1), it follows that $Q_{\lambda s}^*>Q^*$. After rearranging the inequity, we have the results as stipulated in Proposition 2(2).

Q.E.D.

Proposition 2 reveals that both subsidy and the shortage cost play positive roles to stimulate more production quantity. An interesting result is that, under the certain condition, a loss averse manager will produce more products than an optimal quantity in risk neutrality, as evidenced by $Q_{\lambda s}^*>Q^*$. This is in contrast to conventional result that a loss averse manager always produce less if shortage cost is not considered.

Let $EU(\pi_\lambda^*)$ be the loss averse manager's optimal expected utility without considering the shortage cost. We have the following proposition regarding the expected utilities.

Proposition 3. (1) $EU(\pi_{\lambda s}^*)$ is decreasing in g.

(2) $EU(\pi_{\lambda s}^*)$ is increasing in Y.

(3) $EU(\pi_{\lambda s}^*)<EU(\pi_\lambda^*)<EU(\pi^*)$.

Proof of Proposition 3

For 3(1) and 3(2), the optimal expected utility can be written as follows:

$$EU(\pi_{\lambda s}^*)=(p+Y-s)\int_{x=0}^{Q_{\lambda s}^*}xf(x)dx-g\int_{x=Q_{\lambda s}^*}^{\infty}xf(x)dx+(\lambda-1)(p+Y-s)\int_{x=0}^{q_o(Q)}xf(x)dx-g(\lambda-1)\int_{x=q_s(Q)}^{\infty}xf(x)dx$$

Taking the first derivative of $EU(\pi_{\lambda s}^*)$ with respect to g and Y, we obtain

$$\frac{\partial EU(\pi_{\lambda s}^*)}{\partial g}=-\int_{x=Q_{\lambda s}^*}^{\infty}xf(x)dx-(\lambda-1)\int_{x=q_s(Q)}^{\infty}xf(x)dx<0$$

$$\frac{\partial EU(\pi_{\lambda s}^*)}{\partial Y}=\int_{x=0}^{Q_{\lambda s}^*}xf(x)dx+(\lambda-1)\int_{x=0}^{q_o(Q)}xf(x)dx>0$$

For 3(3), because the optimal quantity Q^* in the standard model with subsidies is unique, any other order $Q \neq Q^*$ will decrease the utility. Hence $EU(\pi_\lambda^*)<EU(\pi^*)$. According to Proposition 3(1), the expected utility decreases in g. Therefore $EU(\pi_{\lambda s}^*)$ is less than $EU(\pi_\lambda^*)$ (where g = 0), i.e., $EU(\pi_{\lambda s}^*)<EU(\pi_\lambda^*)$.

Q.E.D.

Proposition 4. (1) q_o is decreasing in Y; q_s is increasing in Y.

(2) If $(p + Y + g - c) > \pi_{loss}$, then $\partial Y/\partial\lambda < 0$. Otherwise, $\partial Y/\partial\lambda > 0$.

(3) $\partial Y/\partial s < 0$.

(4) $\partial Y/\partial g < 0$.

Proof of proposition 4.

For 4(1), the proof is straightforward. Because Y is in the denominator in Eq.(2), the larger the Y is, the smaller the q_o will be. Similarly, Y is in the numerator in Eq.(3), the larger the Y is, the greater the q_s will be.

For 4(2), taking the partial derivative of Y with respect to λ, we have:

$$\frac{\partial Y}{\partial\lambda} = -\frac{\partial^2 EU(\pi)/\partial Q\partial\lambda}{\partial^2 EU(\pi)/\partial Q\partial Y} = -\frac{(p+Y+g-c)-\pi_{loss}}{\lambda - F(Q) - (\lambda-1)F(q_s(Q))}.$$

If $(p + Y + g - c) > \pi_{loss}$, $\partial Y/\partial\lambda < 0$. Otherwise, $\partial Y/\partial\lambda > 0$.

Similarly, for 4(3), taking the partial derivative of Y with respect to s, we have:

$$\frac{\partial Y}{\partial s} = -\frac{\partial^2 EU(\pi)/\partial Q\partial s}{\partial^2 EU(\pi)/\partial Q\partial Y} = -\frac{F(Q) + (\lambda-1)F(q_o(Q))}{\lambda - F(Q) - (\lambda-1)F(q_s(Q))} < 0.$$

For 4(4), taking the partial derivative of Y with respect to g, we have:

$$\frac{\partial Y}{\partial g} = -\frac{\partial^2 EU(\pi)/\partial Q\partial g}{\partial^2 EU(\pi)/\partial Q\partial Y} = -\frac{\lambda - F(Q) - (\lambda-1)F(q_s(Q))}{\lambda - F(Q) - (\lambda-1)F(q_s(Q))} < 0.$$

Q.E.D.

Proposition 4 reveals several implications for policy makers. As shown in Proposition 4(1), subsidy helps decrease the entrance requirement of NEV production by lowering the startup breakeven quantity. Subsidy also helps reduce the stockout risk by increasing the breakeven quantity of shortage. However, the interactions between subsidy and loss aversion is not straightforward when considering the shortage cost, as demonstrated by Proposition 4(2). The increase or decrease of subsidy depends on the trade-off between $(p + Y + g - c)$ and π_{loss}. Proposition 4(3) and 4(4) show subsidy is decreasing in both the salvage value and the stockout cost. It may imply that subsidy can be used as the lever to regulate the possible overages as well as shortages.

4. Concluding remarks

In this paper, we present an analytical model to investigate how the optimal NEV production strategy is influenced by subsidy, overage risk, underage risk, and loss aversion. We find that a loss averse decision maker may produce more production quantity than the optimal quantity in risk neutrality under the certain conditions. We demonstrate that the expected utility is substantially influenced by subsidy, loss aversion, and the shortage cost. Although the relationship between subsidy and loss aversion is not straightforward when considering shortage cost, subsidy may play a role to regulate the possible overages and shortages in NEV manufacturing.

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